RESEARCH HIGHLIGHT

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Development and Assessment of Crawl Space Remediation Strategies

INTRODUCTION

A field investigation documented the long-term durability and effectiveness of crawl space remediation strategies. Over a number of years, the study authors developed comprehensive crawl space remediation strategies and have supervised their implementation in major buildings. The study investigated crawl spaces that had been remediated over seven years in eight major buildings. This report summarizes the key, initial, *in-situ* performance deficiencies, re-design objectives and long-term performance improvements.

Research Project Objectives

The objectives were to provide technical information about:

1. The major details of the original crawl space performance failures.
2. The key remediation strategies and techniques addressing the causes of failures.
3. The long-term performance and current condition of the remediated crawl spaces.

METHODOLOGY

Researchers reviewed more than 30 field records from completed crawl space remediation projects. The review identified an age-stratified sample of eight projects that provided a cross-section of information about crawl space configurations and issues.

Each of the eight project files was examined in detail and a summary prepared of information about underlying problems and the remediation plan. A detailed field inspection assessed the current condition of the building. This information was used to prepare an individual project case study report.

Crawl Space Issues

For each project, an initial information review identified and documented the causes of the original problems. Common issues included:

- Entry of exterior water as a result of improper landscaping or poor management of rain water and snow accumulation.
- Entry of interior water from sewer line failures, piping leaks or inoperable sump pumps. In some cases, the crawl space contamination was further advanced from the application of hydrated lime, bleach or other chemicals in an attempt to control odours.
- The lack of any "system" to provide an effective environmental separation for the crawl space floor assembly. At best, sheets of polyethylene were layered onto the excavation, without any detailed method for attachment, or sealing edges or penetrations. Adding a surface layer of sand created an ideal environment for retaining moisture and contaminants. The sand also prevented cleaning.
- Interior insulation that did not control moisture or air leakage, resulting in significant surface condensation and moisture damage of rim joists and wood framing. In addition to extensive mold growth, there was rotting and structural deterioration.
- Contamination of the space by pests, including insects, mice, rats, bats, snakes and amphibians. The extensive placement of poison bait contributed to the accumulation of carcasses and the presence of poisonous materials in the non-cleanable sand–soil floor surface.
- Microbial contamination from mold growth on wetted paper, wood, food containers, air filters, packaging from repair parts and other debris. This was often compounded by piles of garbage and sheets of cardboard or wood placed on the wet floor by service personnel trying to avoid working on wet, muddy floors.

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- Physical hazards from broken glass, wood with nails, metal shards, abandoned repair parts and other garbage left during construction or by service personnel.
- Poorly sealed mechanical equipment (air handlers, cooling–heating coils or fan coils) and ductwork which, when located in a contaminated crawl space, provided a significant pathway for the transport of contamination. Air leakage from supply air ducts often resulted in pressurization of the crawl space relative to the main floor and contributed to air leakage from the contaminated crawl space.
- Limited access, restricted movement and poor lighting contributed to difficult and dismal working conditions and reduced any worker commitment to maintaining or improving the space.

REMEDIATION STRATEGIES

Crawl spaces were remediated by following a detailed project plan. The following are typical remediation tasks.

- Remove all interior insulation to expose the rim joists and grade beam.
- Remove all debris (garbage, construction materials and so on) from the crawl space.
- Perforate or remove the existing floor barrier membrane (remove all exposed polyethylene).
- Remove surface mold by sanding, scraping, and brushing. Bleach was applied in some cases.
- Install mechanical supports for beam ends. Install pressure-treated wood-blocking at all rotted rim joists and seal all edges.
- Install exterior perimeter drainage system at the exterior–interior of the grade beam and connect piping to new, covered and sealed sumps located inside.
- Provide durable downspout extensions to move water away from the crawl space exterior.
- Re-grade the crawl space floor to establish low points at sump openings.
- Excavate exterior and install rigid polystyrene insulation. Backfill and re-grade with a well-compacted clay layer, polyethylene ground cover and washed gravel surface ballast.
- Install a Permalon™ PlyX 200FR floor barrier to provide a durable and airtight environmental separation. Attention to detailing of the barrier is critical to ensure continuity and long-term performance of the connections and attachments.
- Install thin rubber mats to establish durable pathways for inspection and maintenance personnel.
- Conduct detailed final cleaning using HEPA vacuuming and damp wiping of all interior surfaces. Although not required for mold cleanup, due to the rodent contamination in some cases, a bleach solution was sprayed on many interior surfaces.
- Install a dedicated exhaust fan to provide continuous depressurization and ventilation. Although no deliberate ventilation air was supplied to the crawl space, air leakage through the floor assembly (even after extensive sealing) provided approximately 0.3 ach^{-1} (air changes per hour) at a crawl space depressurization of approximately 3–5 Pa.

During remediation, the contaminated work space remained under a negative pressure to prevent contaminants from entering the occupied areas of the building. Workers used personal protective equipment and contaminated materials were removed and properly disposed of daily. Crawl space remediation projects were usually completed within two years, although the intensive on-site work was typically completed in four to eight months.

RESEARCH CONCLUSIONS

This study clearly demonstrates that well-planned and implemented remediation projects can turn highly deteriorated crawl spaces into functional and durable building components that ensure the long-term stability, performance and sustainability of the building. Some of the major conclusions of the study were:

- It is possible to remediate highly compromised crawl spaces and return them to a high level of performance and durability.
- All of the remediation techniques were successful, some were better than others.
- The white, cross-linked, multi-layer, floor barrier is much more durable and easier to visually inspect than polyethylene, and the overall cost difference for the completed project is small.
- Bleaching had no advantage for removing mold or providing long-term performance and caused some damage to piping and other metal surfaces. Basic physical cleaning provided good long-term performance.
- Regular crawl space inspections and maintenance are essential for keeping areas clean and in good condition.
- Exterior landscaping and water management (including snow) are important elements in preventing basic moisture problems.
- Failure to address the basic performance requirements of conditioned crawl spaces results in conditions that compromise the indoor environment and threaten the continuing physical performance and usability of the building.

Remediation costs have increased from the 2002 values of $\$71–134/m^2$ to consistently over $\$200/m^2$. Although expensive, all of the building owners considered the work to be a good investment in extending the building life.

Figure 1 **Crawl space before remediation**
This crawl space is deteriorated and contaminated. The floor is crudely covered with polyethylene sheets and dirty sand. Many components including insulation, wood, gypsum board and piping show signs of extensive water–moisture damage.

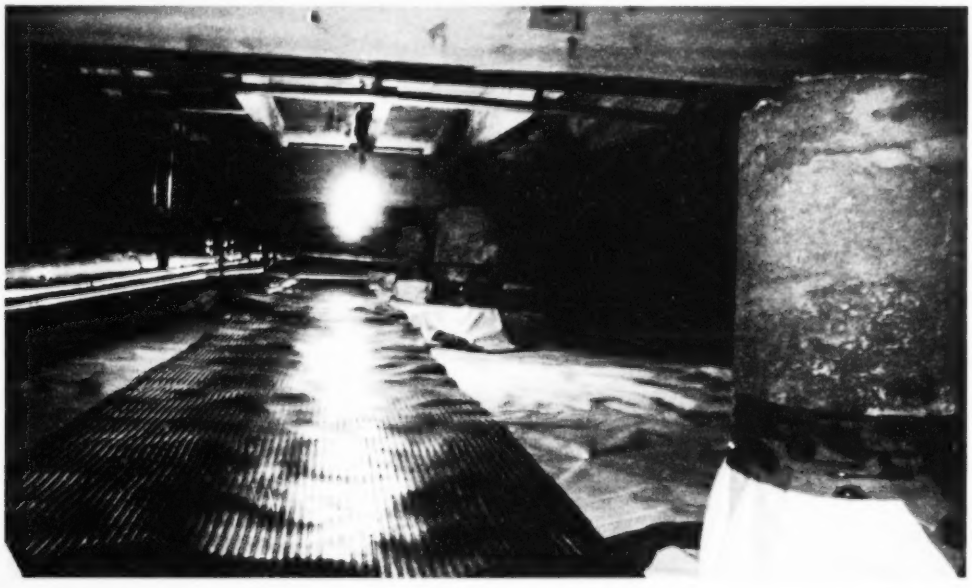

Figure 2 **Crawl space after remediation**
The crawl space has been cleaned and remediated. A durable floor barrier has been installed, and properly sealed at all junctions. Rubber mats have been installed to provide a pathway for maintenance personnel and to provide further protection of floor barrier. Floor barrier extends up the concrete piles and is sealed to enclose the base of each column. Proper lighting has been installed in the crawl spaces.

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